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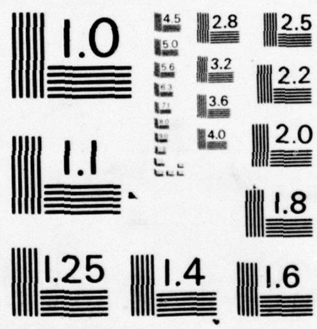

REPORT SAMSO-TR-76-210





# Channel Rate Equalization Techniques for Adaptive Transform Coders

Engineering Science Operations
The Aerospace Corporation
El Segundo, Calif. 90245

15 September 1976

Interim Report

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This report has been reviewed by the Information Office (OIS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions.

FOR THE COMMANDER

Jean Bogert

Jean Bogert, 1st Lieutenant, USAF
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The channel rate equalization problem inherent in a variable rate coding problem is analysed in this paper. Specific solutions are developed for adaptive transform coding algorithms. The actual algorithms depend on either pretransform or post-transform buffering. Simulations indicate small performance variations between the techniques.

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# CHANNEL RATE EQUALIZATION TECHNIQUES FOR ADAPTIVE TRANSFORM CODERS

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## Abstract

The channel rate equalization problem inherent in a variable rate coding problem is analysed in this paper. Specific solutions are developed for adaptive transform coding algorithms. The actual algorithms depend on either pretransform or post-transform buffering. Simulations indicate small performance variations between the techniques.

## Introduction

Although more complex in implementation, adaptive techniques have been demonstrated to outperform nonadaptive procedures by significant margins. An adaptive bandwidth compression procedure by definition "adapts" to the local statistical characteristics of the data. In contrast, a nonadaptive technique presupposes stationarity. The Markov model used by several investigators for transform coding is a well-known (and reasonably successful) example of stationary statistical characterization for images.(1)

The motivation behind adaptive image coding procedures is the necessity to model imagery as a nonstationary source. The bandwidth compression algorithm performs a "learning" procedure by which a localized model is developed, which is, however, only applicable to smaller limited image regions.

In practical terms, adaptivity implies that important parameters of the bandwidth compression algorithm are image dependent. For a fully adaptive technique, the local compression rate is also varying. In contrast, the practical constraint of the fixed rate channel can not be ignored. This appropriate buffering problem associated with variable rate transform coding through fixed rate channels is the objective of the study discussed in this paper. Previous papers(2) on adaptive transform coding have omitted discussion of the buffering problem.

In the following, two fully adaptive transform coding algorithms will be discussed. In addition to some of the superficial similarities to previous procedures, each technique incorporates specific channel rate equalizing methods. It will be shown that both "equalizing" methods strongly influence and interact with the appropriate algorithms.

## Adaptive Transform Coding

Prior to the discussion of specific algorithms, an overview of adaptive transform coding is presented. At first, only elements common to adaptive transform coding are discussed. Actual details of individual algorithms are deferred to the next section.

All adaptive image compression algorithms are based on the concept that some image areas have more detail than others; consequently, they require a larger fraction of the available bandwidth. The equivalent theoretical viewpoint is that all local image regions should have approximately the same amount of distortion resulting from the bandwidth compression. This approach will also allocate more bits to busier image regions. Common to the algorithms to be discussed is that local picture segments are classified according to their structure followed by bit allocation according to classification.

The basic configuration for an adaptive transform coding algorithm is shown in Figure 1. The incoming image is in the form of scan lines which are stored in and reformatted in buffer No. 1. Transform coding algorithms process the data one block (usually square) at a time. Thus, generated bit stream (code words) is stored in buffer No. 2 prior to transmission through the channel. For the actual examples, a $16 \times 16$ block size was chosen. Consequently, 16 scan lines must be stored in buffer No. 1. These 16 lines will be referred to as a "data strip." Similarly, buffers No. 3 and No. 4 perform the same function for the receiver.

The variance of each block is computed and specified as the measure of detail in that block. The actual classification is based on the block variance. Each block is transformed using the Cosine transform.(3) Transform coefficients are quantized(4) according to the conventional bit allocation procedures.

Adaptivity based on local variance is common in the various algorithms discussed in this paper. The required buffering problem, however, is solved differently by each algorithm.

## Discussion of the Specific Algorithms

Two solutions to the channel rate equalization problem have been considered in this paper. They are representative of two classes. For the first class, the bit rate over each data strip is equalized. A sliding window feedback technique is used for the second.

The flow diagram for the first solution is shown in Figure 2.

Algorithm No. 1

In this algorithm, each image block is classified into one of eight classes according to seven total variance threshold levels. These threshold levels must be specified a priori and were chosen with the objective of equal usage of all eight classes. After a data strip enters the first buffer, each block is classified. The actual rate equalization is performed over data strips in the following way: for each class, bit assignment matrices are computed which are expected to produce approximately the same amount of quantization error. Let

$$n_k = \text{number of blocks of class k in the data strip}$$

and

$$\sigma_{ij}^{(k)} = \text{standard deviation matrix element of coefficient i, j for class k}$$

$$b_{ij}^{(k)} = f([\log_2 \sigma_{ij}^{(k)}] - D) \qquad (1)$$

$$= \text{bit assignment for coefficient ij in class k}$$

where

$$f(x) = \begin{cases} \text{integer value of x if } x \geq 2 \\ 0 \qquad\qquad \text{otherwise} \end{cases} \qquad (2)$$

The parameter D is chosen such that

$$\sum_{k=1}^{8} n_k \sum_{i,j} b_{ij}^{(k)} = (16 \times 16 \times R - 3) \sum_{k=1}^{8} n_k \qquad (3)$$

where R is the specified rate for the channel. The class assignments require 3 bits per block. These "overhead" bits account for the bits subtracted from the right-hand side of Eq. (3). Figure 3 is the flowchart for a straightforward iterative computation of D in Eq. (3). Since the parameter D can be computed based on the class codes, it need not be transmitted over the channel.

Algorithm No. 2 (Sliding Window Feedback Technique)

The output buffer status is used in determining the local bit allocation in this algorithm. The important new concept, the sliding windows, is introduced here. Otherwise, the algorithm is based on algorithm No. 1. In the previous algorithm, the coding was performed to yield a fixed bit rate for each data strip. Parameter D is recalculated more often, but the calculation is based on the previous blocks and the current buffer status. Thus, D is being calculated a posteriori instead of a priori.

Figure 4 illustrates the sliding window technique. It is assumed in the figure that steady state has started. The blocks in the window have already been classified and coded. These classifications in conjunction with the buffer status are used to compute D. The next point D is recomputed based on the new window and the new buffer status. Then, the next cycle begins. The equation for computing D is given by changing Eq. (3) to

$$\sum_{k=1}^{8} n_k \sum_{i,j} b_{ij}^{(k)} = (16 \times 16 \times R - 3) \sum_{k=1}^{8} n_k - B \qquad (4)$$

The parameter B, the relative buffer status, serves as the feedback from the output buffer. Specifically, when the "current" rate is the required rate, B is zero. In low detail areas, B tends to be positive and, thus, induces a change in D in order to maintain the required average rate. Similarly, for busy regions B will be negative.

If $n_k'$ is the number of blocks of class k in the blocks to be coded using D, then the new relative coding status, B', after the coding is complete is given by

$$B' = B + \sum_{k=1}^{8} n_k' \left( \sum_{i,j} b_{ij}^{(k)} - 16 \times 16 \times R \right) \tag{5}$$

It should also be noted that the computation of D (via Eqs. (4) and (1)) now only involves previously coded information; thus, D can be recovered from the received data and need not be transmitted.

## Results

Comparison of the two algorithms at various bit rates is shown in Figure 5. The performance criterion is the normalized mean square error (relative to image variances). The performance curves for the two algorithms demonstrate approximately equal results. Pictorial examples are shown in Figures 6 and 7. Because there was no visual difference between the pictorial results for the two algorithms all of the examples are for algorithm No. 1.

## Rate Fluctuation and Relative Buffer Status

The relative buffer status is defined as the local deviation in bits from the exact number specified by the channel rate. It is instructive to analyze this parameter since it is indicative of the buffer utilization. Algorithm No. 1 was used for the various examples.

In Figure 8, the relative buffer status is shown for each block of data processed. It is assumed that the channel decreases the number of bits in the buffer by a fixed value per unit time. The coding algorithm conversely adds bits to the buffer at a variable rate. Since the data strip consists of 32 sub-blocks, the buffer status assumes the value of zero for multiples of 32. On the other hand, at intermediate points the deviation from the "average" value reaches almost 3000 bits.

Figure 9 shows the instantaneous bit rate for this coding algorithm. Note that every block of data was encoded at a different bit rate. Here, the channel rate is 2 bits per pixel. It is evident that the bit rate varies significantly. The cummulative bit rate is shown in Figure 10. The average rate stabilizes at 2 bits as a larger fraction of the image is encoded.

## Conclusions

Two transform coding algorithms have been analyzed according to the problem of channel rate equalization. Classification schemes are utilized to achieve adaptivity. The added consideration of channel rate equalization with an adaptive transform coding algorithm has not been considered previously. The purpose of this paper was to consider two different approaches to the rate equalization problem. In the end result, although these methods were different, there was no visual difference between these pictorial results and little difference in terms of mean square error.

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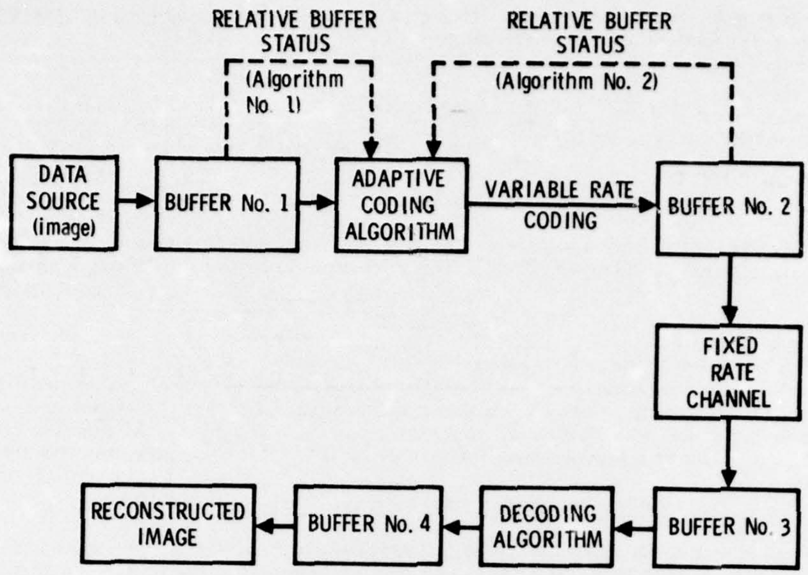



Fig. 1. Adaptive coding procedure.

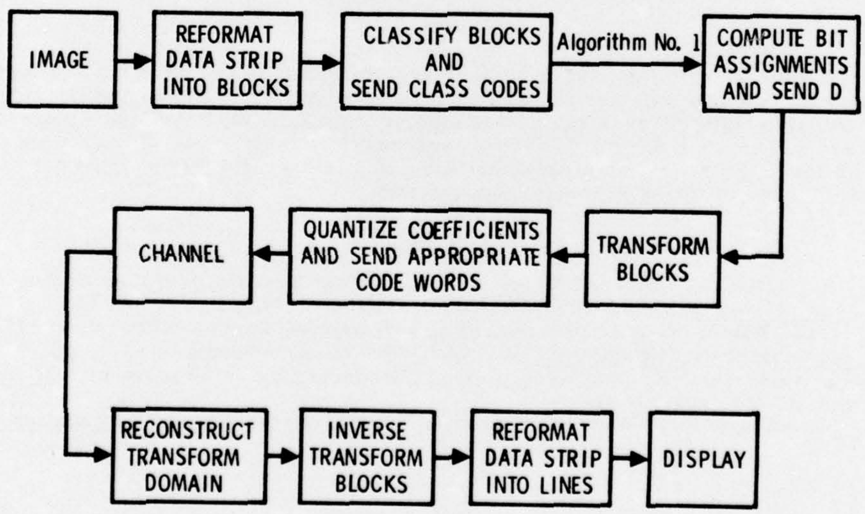



Fig. 2. Schematic diagram for algorithm No. 1.

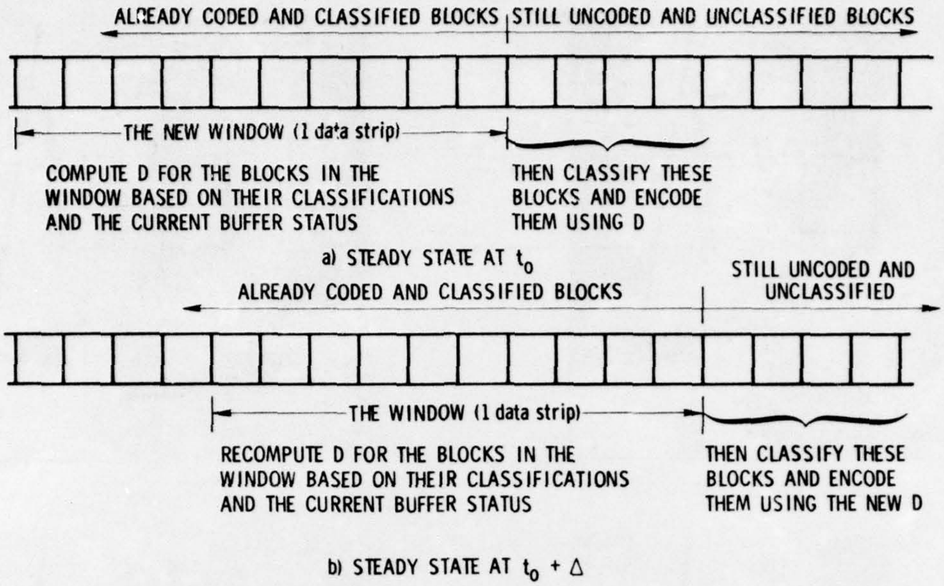



Fig. 4. Illustration of sliding window feedback technique.

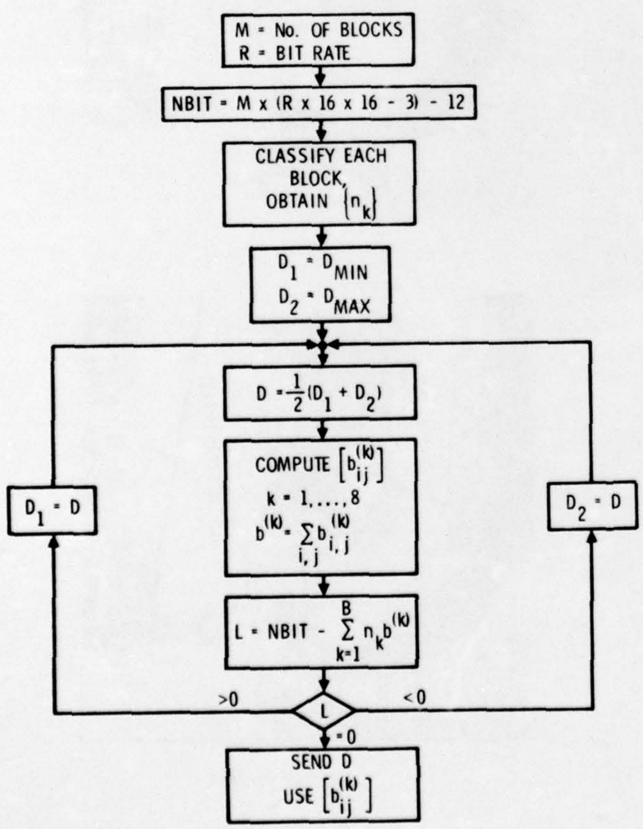



Fig. 3. Bit assignment procedure for algorithm No. 1.

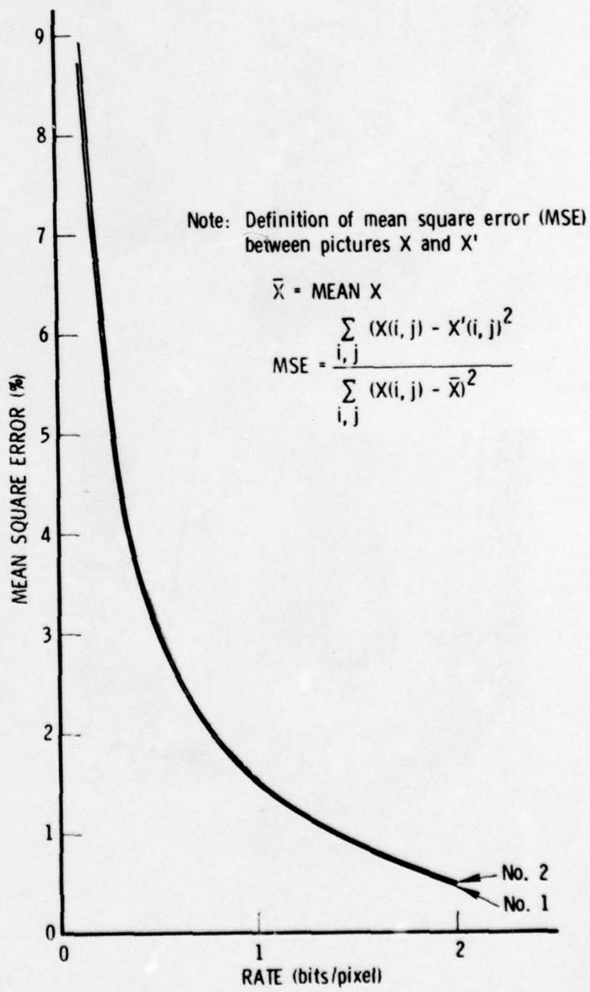



Fig. 5. Performance comparison.

a. Original

b. 2 bits/pixel

c. 1 bit/pixel

d. 1/2 bit/pixel

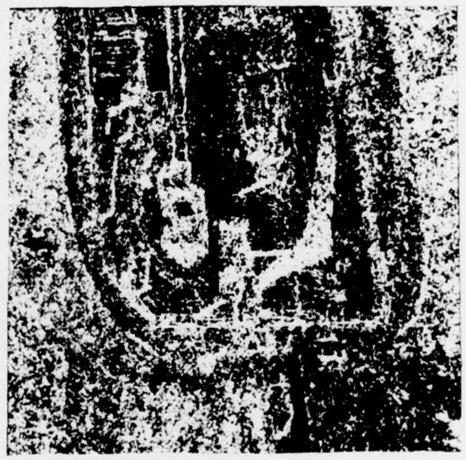
e. 1/4 bit/pixel

f. 1/8 bit/pixel

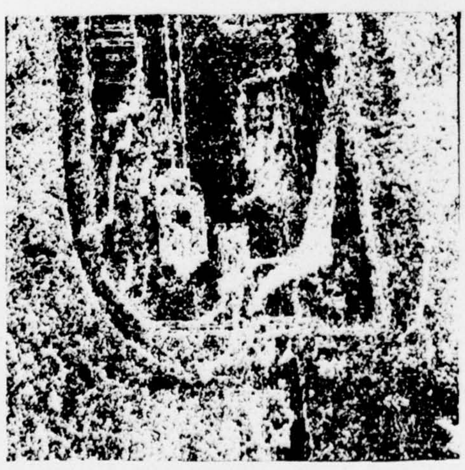
Fig. 6. Coding experiment.

a. 2 bits/pixel

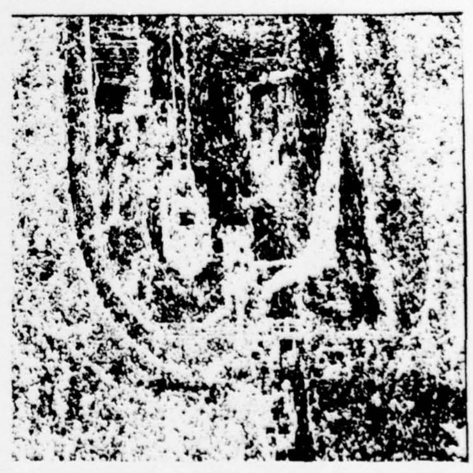
b. 1 bit/pixel



c. 1/2 bit/pixel



d. 1/4 bit/pixel



e. 1/8 bit/pixel

Note: error amplitude magnified 20 times.

Fig. 7. Error images associated with coding experiment.

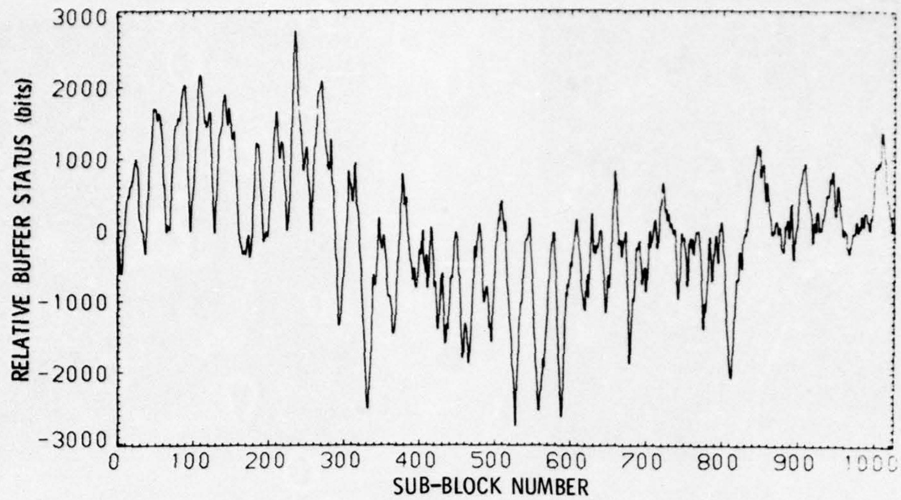



Fig. 8. Buffer status history.

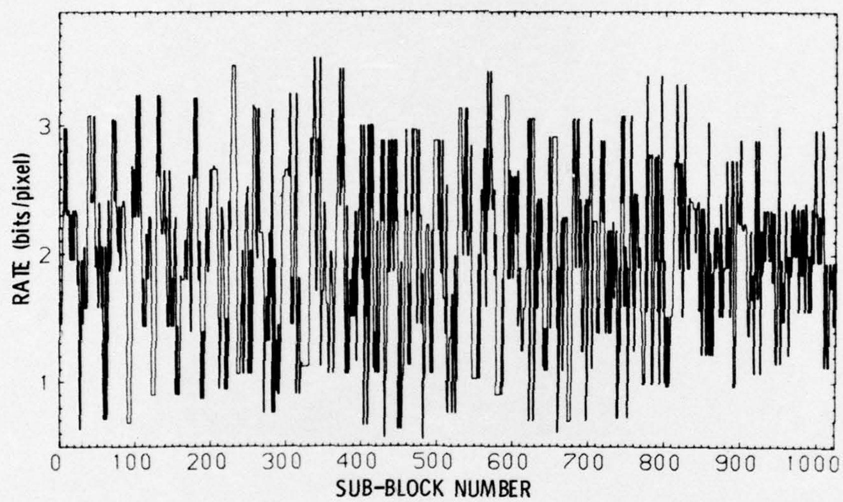



Fig. 9. Instantaneous bit rate.

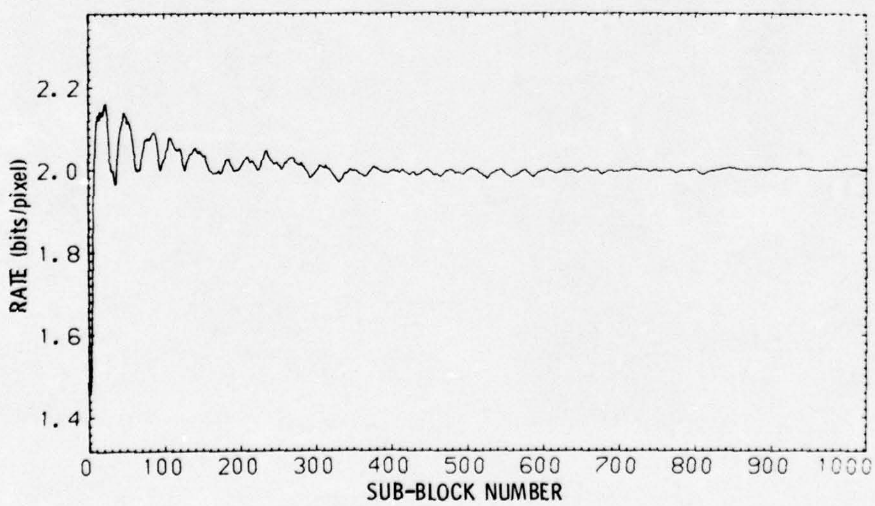



Fig. 10. Average bit rate.